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ABSTRACT

Ideas of optimizing specific objectives were applied to the problem of allocating computer assisted instruction (CAI) time among students in an elementary school. Then, using computer simulation methodology, it was found that simply increasing the total amount of CAI time used could probably improve overall student progress more than any practical allocation strategy. In order to do this, a contest was devised to motivate the students to miss fewer lessons and voluntarily take extra lessons. The CAI program's automatic adjustment of difficulty level allows for a unique kind of academic contest where students of different ability levels have an equal chance of success. The use of the contests appeared to be successful in meeting objectives for system use as well as in generating a great deal of enthusiasm on the part of students. Explicit consideration of overall objectives, use of computer simulation methodology in time allocation, and the use of motivational games in CAI are all potentially applicable in a wide range of CAI settings. (VT)

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# TOWARD OPTIMAL MANAGEMENT OF CAI:

# ALLOCATING INSTRUCTIONAL TIME AND MOTIVATING STUDENTS

by

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# TOWARD OPTIMAL MANAGEMENT OF CAI: ALLOCATING INSTRUCTIONAL TIME AND MOTIVATING STUDENTS

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Computer Curriculum Corporation

In this paper we investigate two questions concerning the optimal management of a CAI system in elementary schools. First, given limited access to the CAI system, what is the best way to allocate available CAI time among the students? And second, how can we motivate students to make the best use of their allocated CAI time even to the extent of voluntarily making up missed sessions or taking extra lessons?

To answer the first question we consider several objectives that might be reached through appropriate time allocations. Examples include maximizing the students' mean grade placement without increasing the variance and maximizing the number of students who make a particular gain. Using an operations research approach, we suggest time-allocation strategies to optimize the chance of reaching each objective. Finally we use learning curves estimated from observed data and a computer simulation of each strategy to predict the outcomes of various allocation strategies.

Our simulation models indicated, somewhat surprisingly, that given reasonable assumptions concerning the ways time can be allocated during a normal school day, different time-allocation strategies make very little difference in overall results. What does make a difference, however, is the total amount of CAI time used by students. For example, the school grade-placement average can be increased as much by increasing total CAI time by ten percent as by any allocation strategy we tested.

These results led us then to the second question of how we can motivate students to use more CAI time. Traditional measures of academic progress such as percentage scores and grade equivalents are not good motivators when used in connection with CAI curriculums and remedial students. Percentage scores are not appropriate because most highly individualized CAI curriculums adjust problem difficulty to keep error rates fairly constant. Additionally, for remedial students it is not usually desirable to reveal true grade placement levels. To avoid these problems and to take advantage of natural social motivations, we devised a CAI contest in which points are accumulated according to the number of correct responses given by individual team members. The number of correct responses provides a good measure of student progress and gives the contest a desirable feature not found in most academic games: the contribution of an individual depends not so much on academic ability as on a willingness to spend time working productively for the team.

## Allocating Available CAI Time

### Progress Objectives and Time Allocation Strategies

In a school with CAI terminals there must be some way of allocating the available terminal time among students. Usually there are some constraints imposed on this allocation by features of the CAI system and by features of the school itself. For example, in our simulations we have assumed that every student is scheduled for one 10-minute lesson per day and that no one receives more than one extra lesson per day. In this way we give every student at least some minimum opportunity to benefit from the CAI program, but we don't schedule anyone for an excessive amount of time in any one day. We have also assumed that five hours of a school day are available for regularly scheduled CAI lessons and one hour is available for extra or make-up lessons.

In addition to constraints, however, any allocation of time among students must use some objective--either implicitly or explicitly. We will try to give a sense of the variety of plausible achievement objectives and the range of time-allocation strategies they imply by discussing six different objectives and the corresponding allocation strategies that seem intuitively to be appropriate. We will see that some of the objectives that seem quite reasonable require allocation strategies that are not particularly appealing. Table 1 summarizes the objectives and strategies. We assume that when students spend time in CAI, they make progress, but some at faster rates than others.

Objective 1: Maximize mean grade placement. Maximizing the mean grade placement appears to be an obvious and reasonable objective. This objective implies that we allocate the available time among students in such a way that the average grade placement of participating students is as high as possible at the end of the school year. Since fast learners by definition make more progress per unit of time than slow learners, the time allocation strategy that optimizes this goal is simply giving all the time to the fastest learners. This strategy has the obvious fault that it does not allow the slow learners any benefit from CAI.

Objective 2: Minimize variance in grade placement. If our objective is to minimize the variance in grade placement, the appropriate time allocation strategy is to give most of the time to the slowest learners and almost none at all to the fast learners. Specifically, the fast learners receive only enough time to keep up with the slowest learners. Under this strategy we hold back the very learners who seem to benefit most from CAI, and, of course, we have a smaller mean grade placement than we would achieve under the first strategy.

Objective 3: Maximize mean grade placement subject to the constraint of not increasing variance. A third objective which is a compromise between Objectives 1 and 2 is to maximize mean grade placement while not allowing the variance to become greater than it

would have been without CAI. To optimize this objective slow learners must be given more time than fast learners, but the differences in amount of time for the two groups would not be as great as in Objective 2.

Atkinson (1972) considered all three of these objectives and recommended Objective 3 as the most desirable and equitable goal for allocating instructional time. Because this objective might not meet the needs of every school environment and for purposes of comparison, we consider several other possible objectives.

Objective 4: Maximize the number of students at or above grade level. Maximizing the number of students at or above grade level holds the same kind of intuitive appeal as maximizing mean grade placement. When we maximize the number of students at or above grade level, we have specified an acceptable achievement level for each student and are not interested in any group averages. We are saying in effect that one student reaching grade level is better than any number of students who almost, but don't quite, reach grade level, and that a student who far surpasses grade level is of no more benefit to optimizing the objective than a student who just barely reaches grade level. To optimize this objective most of the time should be given to students who can just barely reach grade level. No time at all should be given to students who are already above grade level or who would take a very long time to reach grade level. We would rank order the students according to the amount of time they need to reach grade level, and then allocate that amount of time to students beginning with the student who needs the least amount of time and continuing until all of the time has been allocated.

Objective 5: Maximize the number of students who gain one year. For many students, particularly the educationally disadvantaged students, who are presently the primary users of CAI programs, an objective such as Objective 4 is unreasonably high. Often these students are so far below their chronological grade level that to reach that grade level in one year is unrealistic. A more appropriate objective then might be to maximize the number of students who achieve a specified gain such as one year. Objective 5 could also be thought of as an intermediate objective to be used for a year or two before adopting Objective 4. The strategy for optimizing Objective 5 is similar to the strategy for optimizing Objective 4, the only difference being in the acceptable performance level for each student.

Objective 6: Equal time to all students. An egalitarian principle might imply that equal amounts of CAI time should be given to all students without regard to individual learning characteristics. This objective would of course be optimized by a uniform distribution of time across all students.

## Computer Simulation of Different Allocation Strategies

In this section we use a computer model of student progress and

simulate the effects on progress of some of the allocation strategies we have discussed. There are a number of mathematical techniques that can often be used to find optimal solutions (e.g., Cooper & Steinberg, 1970), but these techniques are sometimes difficult or impossible to apply in practice. Therefore, our first steps were to simulate the strategies that would result in approximately the highest and lowest possible values for final mean grade placement. As we will see, the differences between these strategies are not very great.

Prediction equation. In order to simulate the effects of different time allocation strategies we need a model of student progress that predicts grade placement as a function of time spent in CAI. We have previously discussed and statistically compared several such models (Malone, Suppes, Macken, Zanotti, & Kanerva, 1977). For our present purposes we select the model

$$GP(t) = bt^{.45} + c \qquad (1)$$

where $GP(t)$ is the predicted grade placement for a student after $t$ minutes of computer lessons and $b$ and $c$ are learning parameters that are estimated individually for that student. This model had a standard error of fit of .098 for the mathematics curriculum that we use in our simulations here, and a standard error of .072 for the reading curriculum. We found that the model

$$GP(t) = bt^{k} + c \qquad (2)$$

where $b$, $c$, and $k$ are all estimated individually gave slightly lower standard errors of .073 for mathematics and .064 for reading, but we chose not to use this second model for our simulation because of its greater computational complexity.

We estimated the parameters of Model 1 for 2,443 elementary-school students in the Fort Worth Independent School District who were taking a CAI mathematics curriculum developed by Computer Curriculum Corporation. We made these estimates by fitting curves to 15 to 25 data points for each student. The points were approximately evenly spaced throughout the year and consisted of the student's CAI grade placement and corresponding accumulated CAI time. A more detailed description of the students, equipment, curriculum, and data points is given by Malone et al. (1977).

Simulation. Using the individual prediction equations we simulated each student's progress under different time allocation strategies. We allocated time according to a particular strategy, predicted the grade placements that would result after the allocated time was spent, and then allocated more time based on the new grade placements. We repeated this process for 4-week intervals until a whole year had been simulated.

Table 2 gives monthly summaries of the results of such a simulation. Time was allocated according to a uniform distribution with each student receiving six lessons per week. We can think of this as each student receiving one regular lesson per day with extra time

being divided evenly so that each student also receives one extra lesson per week. By the end of the year the mean grade placement for all CAI students had risen from 3.1 to 4.9. The standard deviation of the final grade placement was 1.3 years. Eighty-seven percent (2,134) of the students had reached an arbitrarily designated goal of 1.2 grade years gain.

To examine the magnitude of the effects different allocation strategies have on end-of-year grade placement, we compared the results of the uniform strategy to the results given by the two strategies that would cause the highest and lowest mean final grade placements. We again assume that 5 hours of a school day are devoted to regular CAI sessions during which time each student receives one session; we allow 1 hour per day for extra sessions, and the strategies apply only to this hour. The lowest possible mean final grade placement would be obtained if all of the extra sessions were given to the slowest learners, and the highest mean would be reached if all extra sessions were given to the fastest students.

If we knew precisely the learning curve for each student, we could pick out exactly which students would be the fastest and slowest learners in each month. But our results, reported by Malone et al. (1977), indicate that there is substantial error in estimating the learning curves until near the end of the year. We therefore make the simplifying assumpion that the slowest learners are those who have made the least progress since the beginning of the year, and the fastest learners are those who have made the most progress.

The mean final grade placement, the standard deviation and the percent and number of students who gain at least 1.2 years as a result of each of the three strategies are shown in Table 3. The surprising result is that the mean final grade placments differ by at most .1 grade year and the standard deviations by at most .3 grade years.

These differences do not seem to be significant either practically or statistically. As noted above, when equation 1 is used to predict grade placement, the standard error of fit is .098 grade years, which makes a treatment difference of .1 grade years statistically insignificant.

In terms of practical significance the simplest allocation strategy--dividing lessons evenly among all students--gives results which are almost as good as the strategy that gives all the extra time to the fastest learners. The mean final grade placements are the same and the standard deviations differ by only .1 grade year. What our results seem to indicate is that at least in situations where only 1/6 of the total time is available for extra lessons, it is not not worth the cost to select particular groups of students to use the extra time. It is evidently more important to simply make sure the terminals are being used during the extra time regardless of which students are using them.

Furthermore, if we distribute extra time uniformly and increase the amount of extra time available by 10 percent, we find that each

addition of 10 percent more time for extra sesions adds approximately 0.1 grade year to the final-grade-placement average. These results are shown in Table 4. Again the evidence seems to indicate the importance to student progress of providing as much time for extra sessions as possible and of insuring that the extra time is always used.

## Motivating Students to Use Available CAI Time

Based on these results we considered various ways of encouraging students to spend more time taking CAI sessions. Any alternatives which involved teacher or proctor responsibility seemed undesirable because of the amount of extra work that would be created by the extra scheduling. The best alternative seemed to be to motivate the students themselves to want to spend extra time, and that led us to the idea of implementing computer contests.

We have completed some pilot work in the Houston Independent School District concerning the motivational effects of computer contests played in teams. The individualized nature of Computer Curriculum Corporation's CAI courses made it possible to devise a contest in which winning depended more on each team member's willingness to spend time in CAI than on his or her individual ability or achievement level. The team score was based on the total number of correct answers accumulated by the team members. Because the computer adjusts exercises to individual ability levels, the probability of a correct response is approximately equal across students. Thus, while we expected an individual's contribution to the team score to be directly related to the amount of time he or she spent taking CAI lessons, students were not rewarded for spending time unproductively.

Team scores were computed each week with correct items contributing one point each; items from regularly scheduled sessions, make-up sessions, and extra sessions were all included equally. Scores were adjusted for team size, and weekly winners were announced. The winning team received a small trophy which was held for a week and then presented to the next winner. At the end of the contest period, grand prizes were given to members of the team with the greatest number of total points. In our pilot study, the grand prizes were large "Computer Superstar" decals that could be ironed onto a T-shirt.

Our pilot study indicated that the contests were effective both in generating student enthusiasm and in increasing CAI time and CAI grade-placement gain. The pilot study results also indicated that the contests were more effective when teams consisted of students in the same classroom rather than students who happened to be scheduled in the computer lab at the same time. A more detailed discussion of the data analysis and the results will appear in a later publication.

One issue that is sometimes raised about these contests is whether or not they encourage undesirable competition. First, it is important to realize that the cooperation between students on the same team may be even more important than the competition between students

on different teams. In fact, because of the automatic adjustment of problem difficulty to student ability, these contests may be one of the very few situations where low ability students can contribute on an equal basis to an academic goal that is important to both them and their peers. There could also be non-competitive versions of these contests (e.g., each team working independently for separate rewards), and we think these alternatives are worth investigating.

## Conclusion

In the first part of this paper we showed how ideas of optimizing specific objectives could be applied to the problem of allocating CAI time among students. Then using computer simulation methodology we found that, for our courses and students, simply increasing the total amount of CAI time used could probably improve overall student progress more than any practical allocation strategy. In other words, administrative time in a CAI program may be better spent trying to increase the total amount of time a CAI system is used rather than trying to allocate a small number of extra lessons to a few students.

In the second part of the paper we briefly described one way of trying to increase the total amount of time a CAI system is used. Rather than require the burdensome administrative task of scheduling students for additional lessons, we devised a contest to motivate students themselves to miss fewer lessons and voluntarily take extra lessons. The CAI program's automatic adjustment of difficulty level allows for a unique kind of academic contest where students of different ability levels have an equal chance of success. The use of the contests appeared to be successful in meeting our objectives for system use as well as in generating a great deal of enthusiasm on the part of students.

We feel that the three main topics discussed here--the explicit consideration of overall objectives, the use of computer simulation methodology in time allocation, and the use of motivational games in CAI--are all potentially applicable in a wide range of CAI settings. Now that many of the basic problems of implementing CAI have been solved, it is time to devote some of our attention to broader issues of instructional design. We hope that our work described here provides at least a start in that direction.

## References

Atkinson, R. C. Ingredients for a theory of instruction. American Psychologist, 1972, 27, 921-931.

Cooper, L., & Steinberg, D. Introduction to Methods of Optimization. Philadelphia: W. B. Saunders Co., 1970.

Malone, T. W., Suppes, P., Macken, E., Zanotti. M., & Kanerva, L., Projecting student trajectories in a computer-assisted instruction curriculum. Manuscript submitted for publication, 1977.

Table 1

Alternative Objectives and Strategies
for Allocating CAI Lesson Time Among Students

| Objective | Strategy |
|---|---|
| 1. Maximize mean grade placement. | Give most time to fastest learners. |
| 2. Minimize variance. | Give almost all time to slowest learners. |
| 3. Maximize mean grade placement subject to not increasing variance. | Give more time to slower learners but not as much as 2. |
| 4. Maximize number of students at or above grade level. | Give most time to students who can barely reach grade level; give no time to students who are already above grade level or who would take a very long time to reach grade level. |
| 5. Maximize number of students who gain at least one year or some other goal expressed in amount of gain. | Give most time to students who can just barely reach goal; give no time to students who have already reached the goal or who would take a very long time to reach it. |
| 6. Equal time to all students. | Uniform assignment of time. |

Table 2

Simulation of Model 6, Equal Time to All Students,
for 2443 Ft. Worth Students in Grades 3-6:
All Students Receive 5 Regular and 1 Extra
Mathematics Sessions per week
Progress is Predicted by the Equation,

$$GP(t) = bt^{.45} + c$$

| Week | Mean grade placement | Standard deviation | Number and percent of Students who gain at least 1.2 years | |
|---|---|---|---|---|
| 4 | 3.12 | .83 | 25 | (1%) |
| 8 | 3.47 | .91 | 447 | (18%) |
| 12 | 3.76 | .98 | 1050 | (43%) |
| 16 | 4.00 | 1.05 | 1442 | (59%) |
| 20 | 4.22 | 1.11 | 1730 | (71%) |
| 24 | 4.41 | 1.17 | 1888 | (77%) |
| 28 | 4.59 | 1.22 | 2002 | (82%) |
| 32 | 4.76 | 1.27 | 2072 | (85%) |
| 36 | 4.91 | 1.31 | 2134 | (87%) |

Table 3

Simulation of Student Progress in Mathematics
Resulting From Three Different Time Allocation Models;
N = 2443

| Allocation Model | Mean grade placement | Standard deviation | Number and percent of Students who gain at least 1.2 years | |
|---|---|---|---|---|
| 1. Maximize mean grade placement | 4.9 | 1.5 | 2048 | (83%) |
| 6. Equal time to all students | 4.9 | 1.3 | 2134 | (87%) |
| Lower bound: minimize mean grade placement by giving all extra lessons to slowest learners | 4.8 | 1.2 | 2247 | (92%) |

Table 4

Simulation of Student Progress in Mathematics
Resulting from Increasing Time Available for Extra Sessions
and Allocating Extra Time by Model 6,
Equal Time for All Students;
N = 2443

| Percent of Increase in Extra Time | Mean grade placement | Standard deviation | Number and Percent of students who gain at least 1.2 years | |
|---|---|---|---|---|
| 0 | 4.7 | 1.2 | 2033 | (83%) |
| 10 | 4.8 | 1.3 | 2089 | (86%) |
| 20 | 4.9 | 1.3 | 2134 | (87%) |
| 50 | 5.2 | 1.4 | 2195 | (90%) |
| 100 | 5.6 | 1.5 | 2254 | (92%) |